EXPERIMENTAL INVESTIGATION OF NATURAL FILLER / FIBER REINFORCED HYBRID MATRIX COMPOSITE FOR AUTOMOBILE APPLICATIONS

A SYNOPSIS

Submitted by

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1. INTRODUCTION

Researchers have significantly advanced the use of natural fillers and fibers across various applications. These materials offer numerous benefits compared to synthetic alternatives, such as higher strength-to-weight ratios, lower density, widespread availability, and enhanced strength. Bio based plastic goods and biodegradable polymers, derived from renewable resources, offer promising alternatives for environmentally friendly and sustainable products, capable of competing effectively in today's market, as demonstrated by studies [1]. Geopolymers are sustainable building materials with low carbon footprints, enhanced durability, and strong mechanical properties. Developed lightweight geopolymer composites using metakaolin and 5-10 wt% cork dust, an industrial by-product, added before and after alkaline activation with sodium hydroxide and sodium silicate. The composites showed stable chemical properties, reduced density, porosity, and antibacterial activity. With compression strength from 15 to 5 MPa, these materials offer potential as durable, eco-friendly interior panels [2]. Tensile and flexural properties of Casuarina equisetifolia composites at weight loadings ranging from 10% to 50%. The tensile strength and modulus decreased as the Casuarina equisetifolia content increased, though the decline in tensile modulus was not significant. At 20% weight loading, the flexural modulus and strength peaked respectively, but further increases in Casuarina equisetifolia content led to a decline in these properties [3]. Sansevieria trifasciata (snake plant) fibers with epoxy resin, prepared through a manual hand lay-up process with varying reinforcement (10%, 20%, 30%). Mechanical testing revealed that the 30% fiber composite had superior Mechanical Qualities, related to other materials. SEM analysis showed strong fiber-resin bonding, while FTIR indicated reduced hemicellulose and lignin, improving adhesion. The water absorption of the composites increased over time, with the 30% fiber sample having the highest absorbency [4]. The production of synthetic fibers is steadily declining due to the decreasing availability of crude and mineral oils. These fibers contribute to environmental pollution, and their disposal, recycling, and processing release large amounts of greenhouse gases, posing direct risks to both humans and animals [5]. Consequently, numerous industries, including aerospace, automobile, navy, construction, and manufacturing, are progressively prioritizing the development of advanced lightweight Nano composite

materials.. The production of lignocellulosic materials is growing annually, driven by the use of natural agricultural resources as an alternative to synthetic fibers [6]. This research investigated the low-velocity impact behavior of three materials: pineapple leaf fiber (PALF)-reinforced epoxy composite (P), PALF hybrid composite (GPG), and four-layer woven glass fiber composite (GGGG).Post-impact analysis using photographic images and CT scans revealed that the GPG hybrid composite showed delayed damage initiation and propagation compared to GGGG, indicating a positive hybrid effect. Visual inspection showed different damage modes for GPG and P, while CT scans highlighted extended internal damage in all impacted composites. The addition of PALF demonstrated properties comparable to fully synthetic composites [7]. This study developed intra-ply Kevlar/hemp fiber (KHE) reinforced epoxy hybrid composites with different weaving designs, analyzing their thermal properties. Plain and basket weaves showed the highest thermal stability, while basket weave offered superior dimensional stability. Twill weave composites exhibited the best mechanical performance, with the highest storage and loss moduli. Overall, the enhanced thermal performance makes these composites suitable for thermal insulation, fire-resistant clothing, and automotive applications [8]. Snake grass Fibers treated with 5% NaOH was used to fabricate hybrid composites in different ratios (70:30, 50:50, and 30:70) using compression molding. Mechanical tests revealed that the 30:70 (snake grass: sisal) hybrid composite exhibited superior mechanical properties compared to other ratios and performed similarly to sisal mono composites in wear and water absorption tests. Optical microscopy confirmed strong interfacial bonding between fibers and the polymer matrix [9]. This study explores the fabrication of isophthalic polyester composites reinforced with natural fibers such as snake grass, banana, and coir. It compares the tensile and flexural qualities of snake grass fiber-reinforced composites with those of hybrid composites incorporating snake grass/banana and snake grass/coir fibers. Analysis of stress-strain curves and fiber pull-out in fractured specimens revealed that the hybrid composites (snake grass/banana and snake grass/coir) exhibited superior tensile and flexural properties compared to the single snake grass fiber composites [10].

2. LITERATURE REVIEW

Ashok et al. [11] discovered that incorporating 2 wt.% lignite fly ash nanofiller into Calotropis gigantea fiber/epoxy composites significantly improves tensile, interlaminar shear, impact, and flexural strength. This enhancement makes the material highly suitable for sustainable brake applications, offering excellent mechanical and tribological qualities. Prem Kumar et al. [12] investigated the mechanical and wear properties of natural fiber-reinforced hybrid composites made from jute, snake grass, and kenaf fibers. The sample with equal proportions of snake grass and kenaf fiber (12.5% each) showed excellent mechanical strengths, while the addition of 5 wt% Annona reticulata seed powder improved wear resistance.

Mateusz Barczewski et al. [13] Polypropylene composites filled with sunflower husk were produced, enhancing sustainability despite slight reductions in mechanical properties. The filler increased stiffness and showed good adhesion without surface modifications, while maintaining aesthetics and reducing cost, though higher filler content reduced elongation at break and ductility. Shanti et al [14] develop glass fiber reinforced composites with synthetic and natural fillers, namely graphite and various wood fillers. This study clearly demonstrated that graphite filled glass fiber composites exhibit more mechanical and thermo mechanical strengths compared the composite without filler.

Jenish et al. [15] explores the enhancement of interfacial bonding in snake grass fiber (25wt.%and 30 mm fiber length)-reinforced polyester composites through various chemical treatments, with calcium carbonate treatment yielding the best mechanical and tribological properties. Mekonnen et al. [16] The result indicated that the hybrid composite with 10 percentage jute, 20 percentage bamboo and 70 percentage polyester shows peak tensile strength (yield strength of 72.03 MPa) compared to other combinations examined, and the hybrid composite with 0 % jute, 30 percentage bamboo and 70 percentage polyester shows the maximum flexural strength (133.9 MPa). The elongation of jute-reinforced composite was found to be the longest in the tensile test (2.98 mm).

Nagarajan et al. [17] α-cellulosic micro fillers from Cocos nucifera var Aurantiaca

Peduncle (CAP) have been used as a reinforcing material in epoxy polymers, showing improved mechanical properties with filler loading from 3 wt% to 15 wt%, with 15 wt% demonstrating superior performance. Prabhu Loganathan et al. [18] The study revealed that hybridizing snake grass fiber (SGF) and waste tea leaf fiber (WTLF) composites with glass fiber significantly improved their mechanical properties. A composite with 25 wt.% showed a high acoustic absorption coefficient (AAC) of 0.59 in the 2000–6300 Hz range, indicating potential for soundproofing applications like loudspeakers and recording rooms.

Gurukarthik Babu et al [19] investigates hybrid natural fiber composites using alkali-treated Phaseolus vulgaris fiber (PVF) and nanosilica with varying weight percentages, showing optimal electrical, thermal, and mechanical properties at 6% PVF and 1% SiO2. Beyond 6% PVF, properties decline, except for thermal conductivity and water absorption, which increase. Alshammari et al. [20] used date palm fibers, particularly fruit bunch stalk (AA) filler, in an epoxy matrix, significantly improving the composite's mechanical strength, moduli, and physical properties compared to pure epoxy. Similar enhancements were observed in water absorption and density.

Abral et al. [21] demonstrates that the stacking sequences of rice husk/starch fibers significantly affect thermal conductivity, with the RH40 mode (15% starch) achieving a conductivity of 2.6 W/m·K, a 472.72% improvement over pure resin. This suggests that rice husk/starch fiber composites are effective insulating materials for engineering applications. Chandramohan et al. [22] investigates the development of polymer bio-composites using powdered coconut shell, walnut shell, and rice husk as reinforcements in bio epoxy resin. The test results show that the hybrid composite exhibits significantly better mechanical properties compared to single fiber glass-reinforced composites. Incorporating walnut and coconut shell fibers notably enhances the composite's performance.

Kuburi et al. [23] find the 15 % of Coconut shell-filled composites using recycled low-density polyethylene showed increased tensile strength, flexural strength, and hardness up to specific limits, with a reduction in impact energy as fiber length increased. The addition of fiber from 0 to 10 mm reduced the composite's density and increased its water absorption. Sathish et al. [24] studied the effect of volume fraction on the mechanical and physical properties of flax and bamboo fiber-reinforced epoxy composites. SEM and FTIR analyses reveal that 40:0 (flax: bamboo) composites provide the best mechanical properties, while 20:20 composites show

reduced void content due to improved fiber-resin compatibility.

Vimalanathan, et al. [25] The study found that polyester composites with 20 v/v% Shorea robusta filler exhibited the best mechanical, dynamic mechanical, and thermal properties. Additionally, filler incorporation improved the composite's thermal stability and biodegradability. Prabhakar et al. [26] demonstrates that groundnut shell reinforcement in polyester composites enhances mechanical and thermal properties, with optimal performance at 15 wt%. These lightweight, cost-effective composites show potential for applications in automotive interiors, electronics, construction, and sports goods. Koutsomito poulou et al. [27] examines recycling olive pits(15%) by blending them with PLA to develop biodegradable composites for containers and formworks. It reveals that different grinding methods affect olive pit powders, leading to increased tensile modulus but reduced flexural strength due to weak bonding with PLA.

This research is noteworthy for its focus on optimizing composite formulations by incorporating epoxy and bio-fillers at varying volume percentages, highlighting the potential of bio-composites as eco-friendly alternatives to conventional plastics. By utilizing renewable resources such as plant fibers, these materials not only reduce carbon emissions and dependency on fossil fuels but also contribute to a more sustainable future. Additionally, the enhanced biodegradability of bio-composites compared to traditional plastics helps mitigate environmental pollution, further emphasizing their ecological benefits.

3. OBJECTIVES

1. To Survey the Various Literature Studies and Identified the Fillers Based On the Gap.
2. To fabricate composite materials with varying volume percentages of Casuarina filler and epoxy resin using the hand layup method, analyze their mechanical properties, and determine the optimal values.
3. To develop composite materials by incorporating cork filler and epoxy resin in varying volume percentages using the hand layup method, evaluate their mechanical properties, and identify the optimal values.
4. To create composite materials with varying volume percentages of snake grass fiber and epoxy resin using the hand layup method, examine their mechanical properties, and determine the optimal values.

5. To fabricate composite material based natural fillers mechanical test optimum value and study the mechanical properties, TGA, DMA, SEM analysis and bio-degradability test and derived the optimum values.
6. To make the small and medium scale components from hybrid composite material.

4. RESEARCH PROBLEMS

a) It was observed from the literatures that limited studies relevant to Casuarina and cork, Snake grass filler in epoxy matrix composites.

b) There are challenges to obtaining proper binding between the matrix and the fiber (natural and synthetic).

c) To fabricate the components with this new hybrid composites.

5. ORGANIZATION OF THESIS

Chapter 1: Introduction

This chapter sets the stage for the study by presenting the context and rationale behind the research. It introduces the significance of biodegradable natural materials such as casuarina, cork, and snake grass. The chapter outlines the research gaps, objectives, and potential contributions to the field of hybrid composites, emphasizing the shift towards sustainable practices.

Chapter 2: Literature Review

The literature review, by providing a comprehensive examination of existing studies related to hybrid natural composites, delves into the role of natural fillers in enhancing material properties and explores the specific application of bio-fillers in small and medium-scale products, while critically evaluating previous findings on the mechanical, thermal, and surface characteristics of reinforced filaments, thereby establishing the foundation for the current study.

Chapter 3: Materials and Experimental Methods

This chapter describes the methodology, beginning with the procurement and preparation of materials, detailing the formulation of fillers/fibre and epoxy composites. It covers the experimental setup, the specific tests performed for material characterization, and the techniques used for analyzing mechanical and thermal properties, as well as SEM analysis.

Chapter 4: Results and Discussion

This Chapter provides a comprehensive analysis of various natural and hybrid epoxy composites, focusing on their mechanical and thermal properties, biodegradability, and microscopic structure. Each section systematically examines different fillers-Casuarina, cork, and snake grass—individually and in hybrid forms, evaluating their influence on the composite's performance. Through techniques such as Dynamic Mechanical Analysis (DMA), Thermogravimetric Analysis (TGA), and Scanning Electron Microscopy (SEM), this chapte`r seeks to identify optimal material properties and analyze the composites' structural integrity and sustainability. The chapter concludes with a summary of key findings, practical implications, and suggestions for future research directions. The subchapter details are as follows,

Chapter 4.1: Mechanical Properties of Casuarina-Epoxy Composites

Chapter 4.2: Mechanical Properties of Cork-Epoxy Composites

Chapter 4.3: Mechanical Properties of Snake Grass-Epoxy Composites

Chapter 4.4: Experimental Investigation of Hybrid Composites

Chapter 4.5: Summary of Findings, Limitations, Practical Applications, and Recommendations for Future Research

Chapter 5: Conclusions

The final chapter synthesizes the findings, drawing conclusions about the effects natural fillers/ fibres in composites. It addresses the research objectives, discusses the implications for the additive manufacturing industry, and suggests areas for future work. The chapter concludes by highlighting the study's contribution to sustainable material development in small and medium scale applications.

6. RESULTS AND DISCUSSION

a. Characterization of Natural fillers with Epoxy composite

Figure 1 provides a graphical representation of the fabrication process for natural filler-reinforced epoxy composites. In this study, mechanical testing and procedures were employed to evaluate the material properties of a hybrid composite developed using Casuarina, cork, and snake grass fillers with epoxy and particle reinforcement. The primary objective of this research is to modify the material composition and analyze the resulting mechanical properties of the fabricated composite.

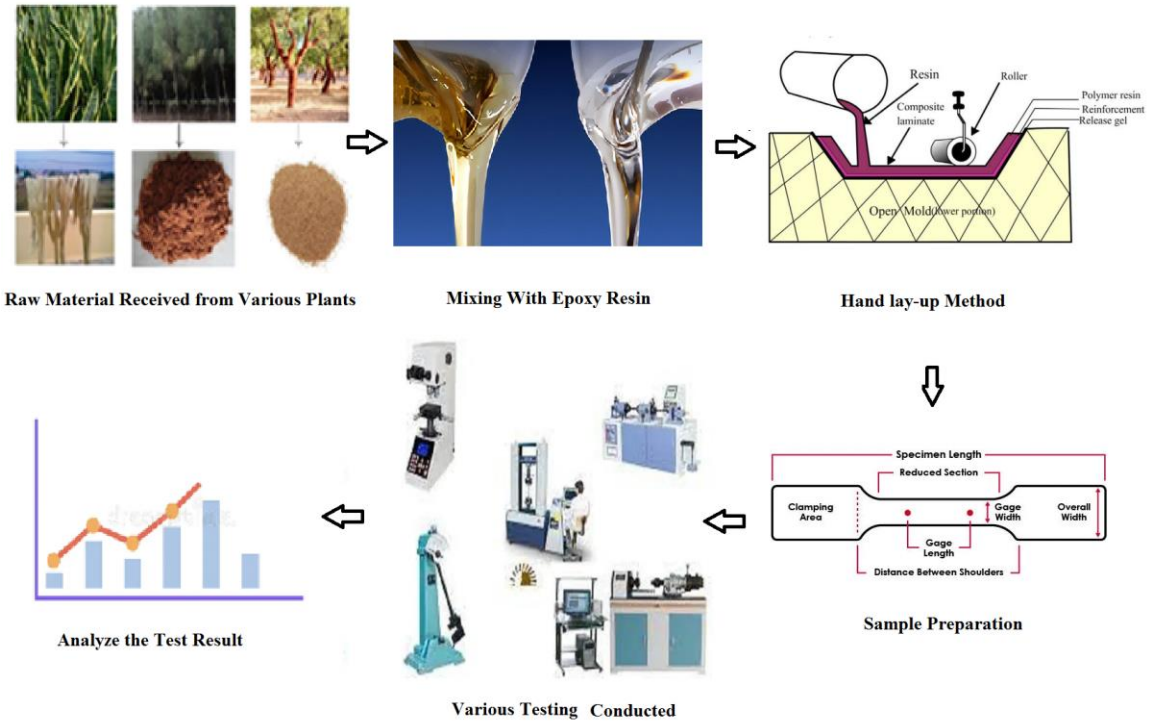

Figure 1 Graphical illustration of Natural fillers with Epoxy composite fabrication

Specimens were fabricated using different proportions of natural fillers, as detailed in Table 1, through the hand layup method. Mechanical testing, including tensile, flexural, and impact tests, was conducted to evaluate the performance of the resulting natural composite material.

Table 1 Composition of Natural fillers with epoxy

Materials	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
Epoxy (%)	100	95	90	85	80	75	70
Casuarina (%)	**0**	5	10	15	20	25	30
Cork (%)	**0**	5	10	15	20	25	30
Snake Grass (%)	**0**	5	10	15	20	25	30

Hybrid epoxy composite was prepared based on the optimum values from natural fillers epoxy composite. Finally three types of epoxy composites were prepared with Casuarina, cork, and snake grass natural fillers in various volume percentages as shown in Table 2.

Table 2 Compositions of Hybrid Composites

Sample ID.	Materials			
	Epoxy (%)	Casuarina (%)	Cork (%)	Snake Grass (%)
Sample-1	80	0	10	10
Sample-2	80	10	0	10
Sample-3	80	5	5	10

b. Mechanical Properties for Natural fillers with Epoxy composite

i. Tensile Properties

Figure 2 illustrates the tensile performance results for natural fillers with varying compositions. The preparation of tensile specimens followed ASTM D3039 standards.

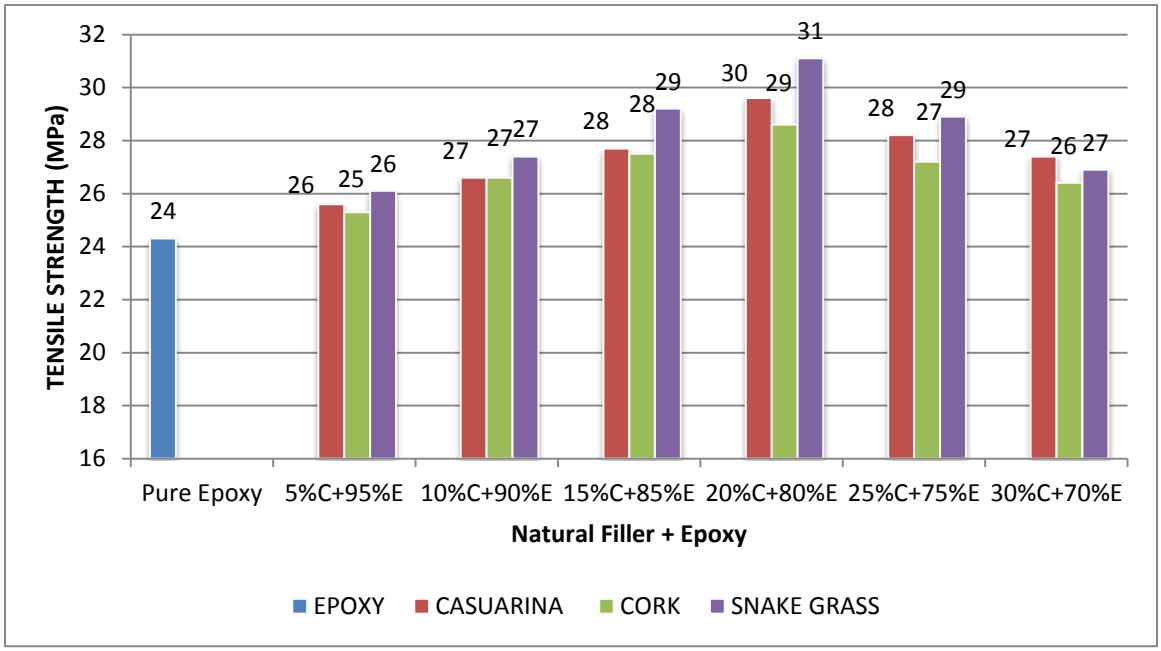

Figure 2 Tensile Test Natural filler Epoxy composite

The tensile strength of Casuarina, cork, and snake grass epoxy composites exceeded that of pure epoxy. In each composite, the optimal results were achieved with a composition of 20% natural filler (Casuarina, cork, or snake grass) and 80% epoxy resin. The tensile strengths were 27.4 N/mm² for Casuarina, 28.8 N/mm² for cork, and 32.1 N/mm² for snake grass. These results highlight the significant impact of fiber volume ratio on the tensile properties of the composite.

ii. Flexural behavior

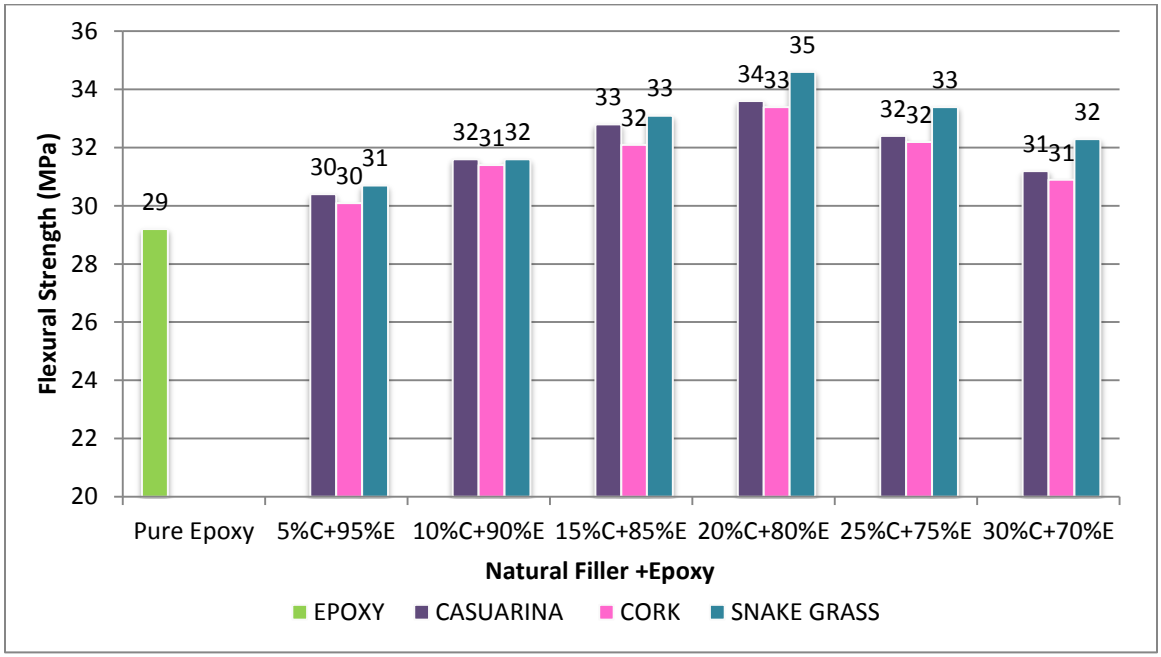

Figure 3 Flexural Test for Natural filler Epoxy composite

Figure 3 presents the flexural performance results for natural fillers with epoxy in various compositions. The preparation of flexural specimens followed ASTM D790 standards. The flexural strength of Casuarina, cork, and snake grass epoxy composites was superior to that of pure epoxy. In each case, the optimal results were obtained with a composition of 20% natural filler (Casuarina, cork, or snake grass) and 80% epoxy resin. The flexural strengths were 34.1 N/mm² for Casuarina, 34.5 N/mm² for cork, and 37.4 N/mm² for snake grass. These findings underscore the significant impact of fiber volume ratio on the composite's flexural properties.

iii. Impact behavior

Figure 4 displays the impact performance results for natural fillers with epoxy in various compositions. The preparation of impact specimens was carried out according to ASTM D256 standards. The impact strength of Casuarina, cork, and snake grass epoxy composites surpassed that of pure epoxy. In each case, the optimal composition consisted of 20% natural filler (Casuarina, cork, or snake grass) and 80% epoxy resin. The impact strengths were 2732 J/m² for Casuarina, 2746 J/m² for cork, and 2763 J/m² for snake grass. These results highlight the significant influence of fiber volume ratio on the composite's impact properties.

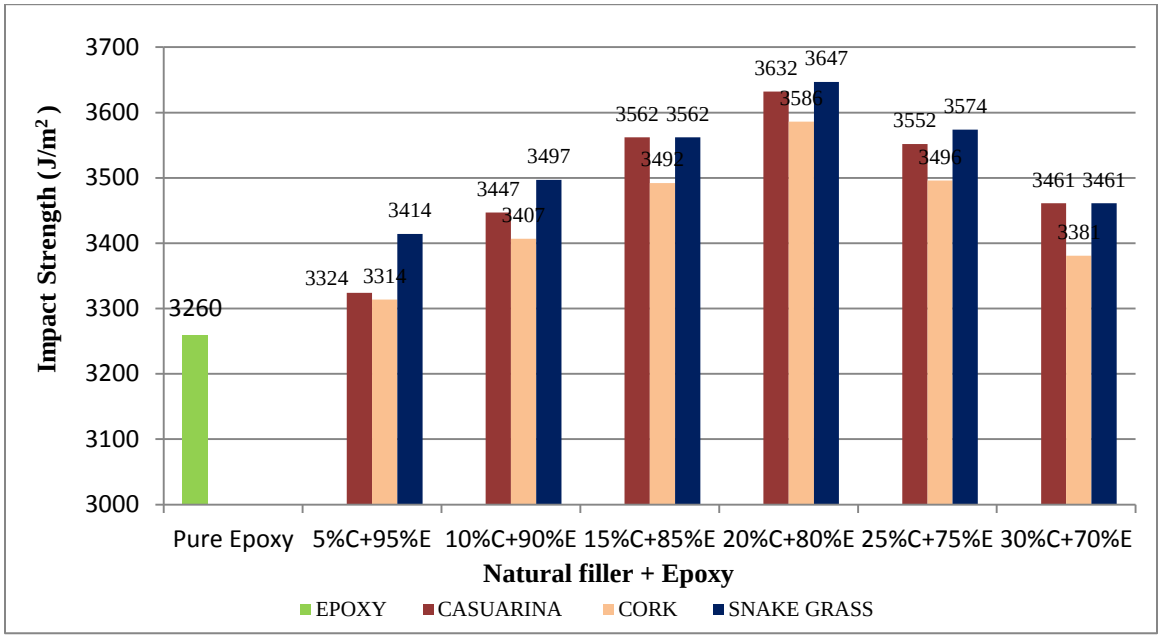

Figure 4 Impact Test for Natural filler Epoxy composite

iv. Biodegradability Testing

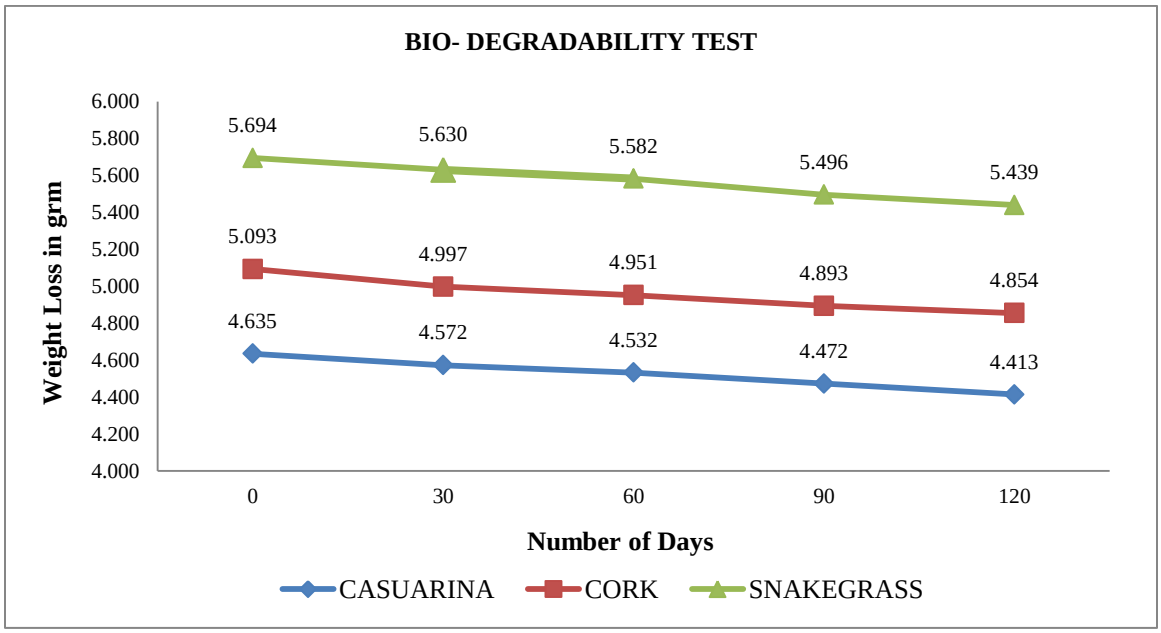

Figure 5 Bio-Degradability Test for Phase 1, 2 and 3

Biodegradability testing was conducted by burying a material sample in damp soil, as shown in Figure 5, to assess the impact on natural filler-blended epoxy polymer materials. The initial weight of the sample was recorded before burial, and measurements

were taken at regular intervals to track any changes. After 120 days, the samples showed a weight loss of approximately 4 to 5 percent. This weight loss was attributed to the interaction with micro- and macro-organisms over time. A comparative analysis with other bio-fiber- and filler-reinforced polymer composites revealed that the cork-blended epoxy material exhibited higher biodegradability. The inclusion of bio-fillers in the epoxy hybrid material enhances its environmental friendliness, contributing to the development of more sustainable polymers

Figure 6 illustrates the tensile performance results for various compositions, showcasing the total tensile strength. The preparation of tensile specimens adhered to ASTM D3039 standards. The tensile results for epoxy composite Samples 1, 2, and 3 were superior to those of pure epoxy. Sample 3, with a composition of 5% Casuarina, 5% cork, 10% snake grass fiber, and 80% epoxy resin, exhibited the optimal outcome, with a tensile strength of 35.4 MPa. These findings highlight the significant influence of the fiber volume ratio on the composite's tensile properties.

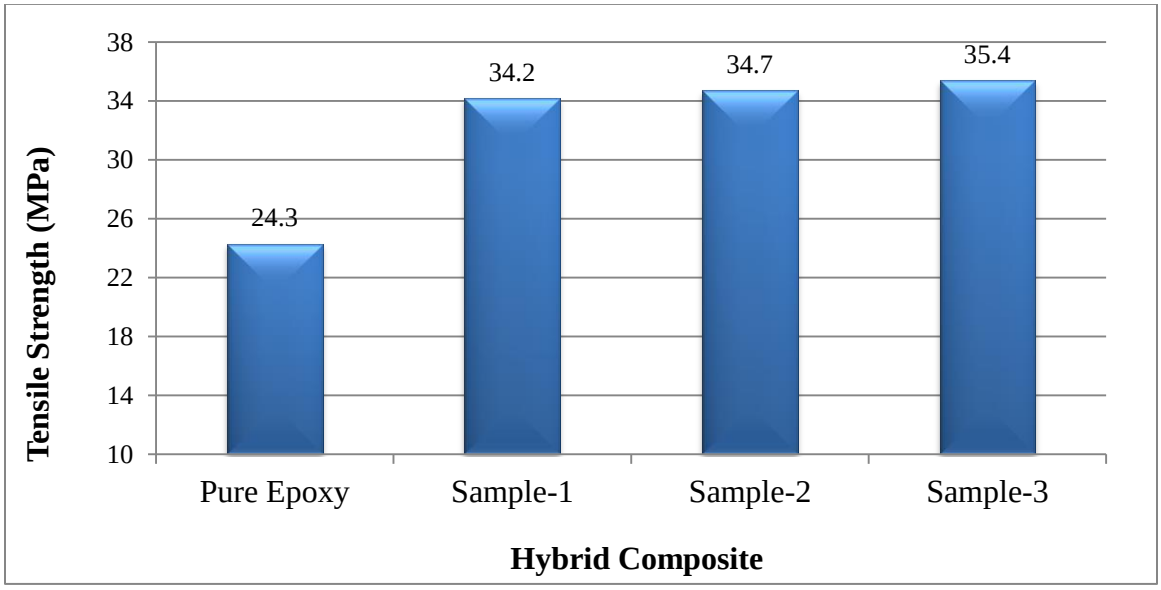

Figure 6 Tensile strength of Bio filler epoxy composite

Figure 7 depicts the variations in flexural strength across different compositions. The preparation of flexural specimens followed ASTM D790 standards. The flexural test results for epoxy composites Sample 1, 2, and 3 were superior to those of pure epoxy. Sample 3, consisting of 5% Casuarina, 5% cork, 10% snake grass fiber, and 80% epoxy resin, exhibited the best performance, with an overall flexural strength of 37.2 MPa and a

modulus of 1390 MPa. This pattern underscores the significant impact of fiber content on the composite's flexural properties.

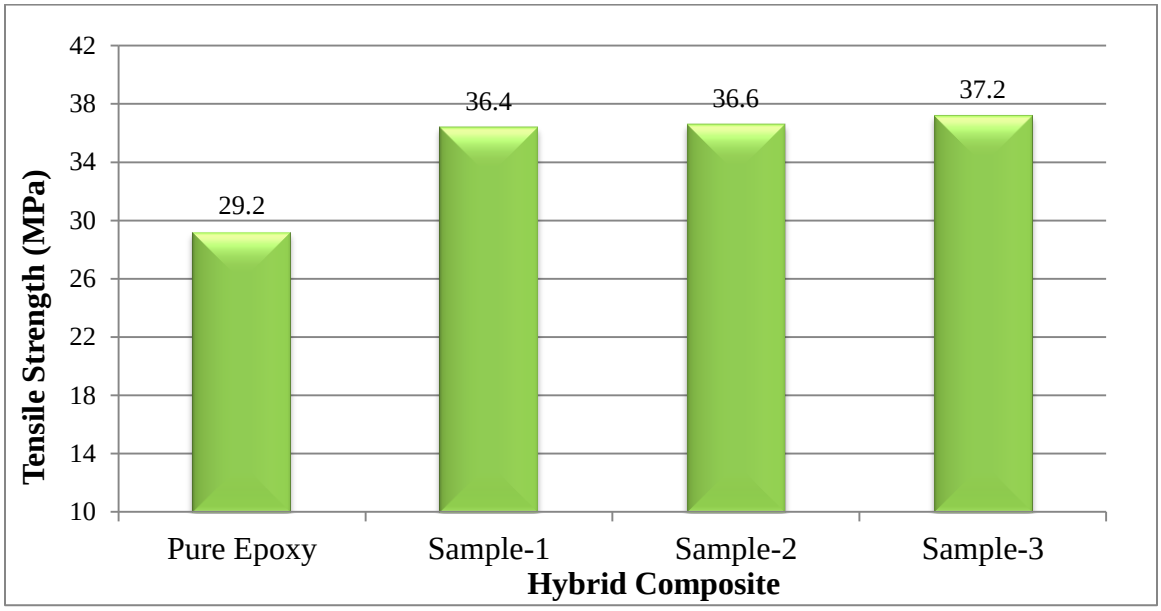

Figure 7 Flexural strength of Bio fillers epoxy composite

Figure 8 shows the variations in impact strength across different mixtures. The preparation of impact specimens was conducted according to ASTM D256 standards.

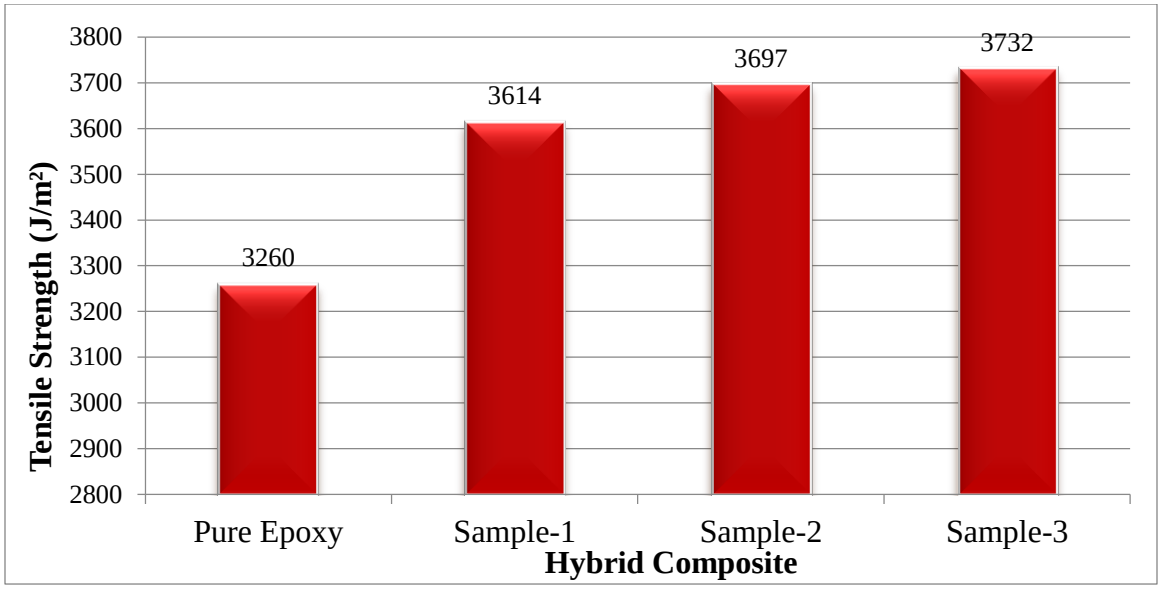

Figure 8 Impact strength of Bio filler epoxy composite

Sample 3, with a composition of 5% Casuarina, 5% cork, 10% snake grass fiber, and 80% epoxy resin, demonstrated the highest impact strength, measuring 3732 J/m², as depicted in Figure 8. The impact test results for epoxy composites Sample 1, 2, and 3 all

surpassed those of pure epoxy.

c. Dynamic Mechanical Analysis of Bio filler epoxy composite

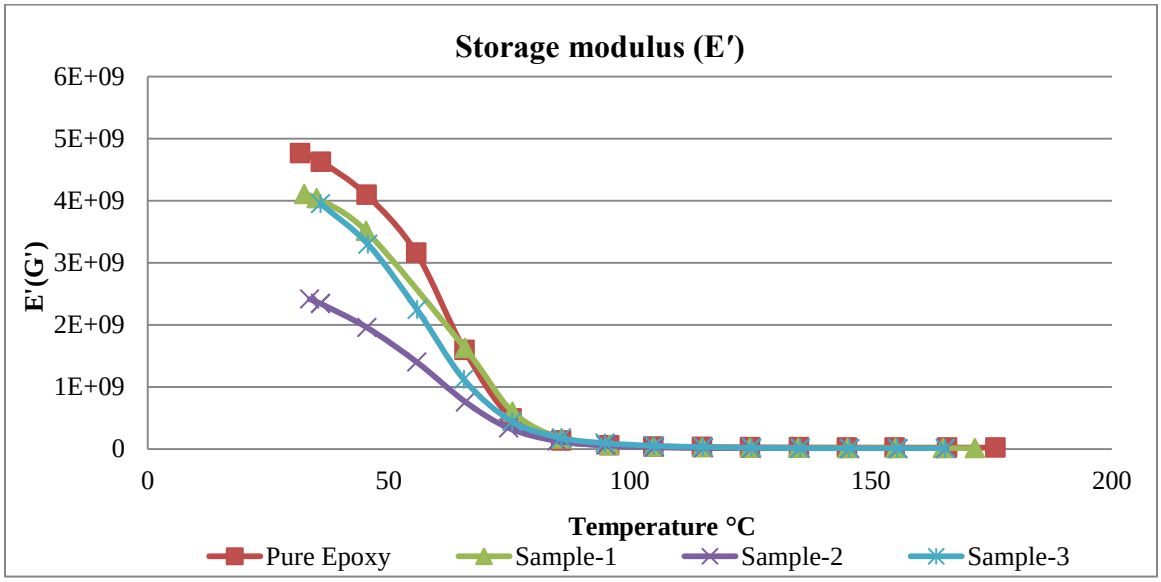

Figure 9 Storage modulus (E′) of Bio filler epoxy composite

Figure 9 shows how temperature and frequency affect a composite material's storage modulus (E′), which is made up of 20% filler and epoxy resin. Between 30 and 200 °C was the test temperature range, and the frequency was 10 Hz. According to the findings, the composite showed a better storage modulus at any frequency up to 110 °C. This implies that the composite material successfully supported the load up to 110 °C . Nevertheless, a steady loss of grip on the matrix may occur above this temperature, potentially impairing their ability to perform as planned.

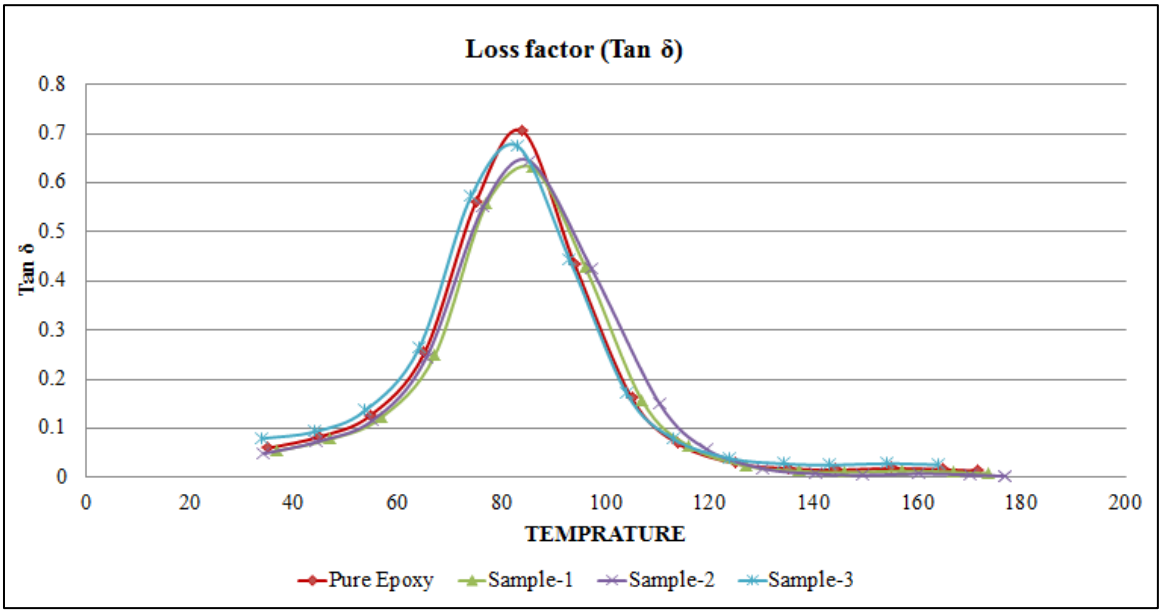

Figure 10 Loss factor (Tan δ) of Bio filler epoxy composite

Figure 10 it's evident from the data that adding reinforcement lowers the composite material's loss component, suggesting that a composite material affects the energy dissipation mechanism instead of just a matrix. The material is thought to be in its energy complex or glass state at lower temperatures. The material passes through a phase transition into the glass transition, sometimes referred to as the elastic or entropy complex state, where the glass phase changes into the elastic flexible phase as the temperature rises. It is common to correlate the maximum loss modulus (E″ max.) or the highest loss factor (tan max.) with the temperature at which this transition takes place. In this study, the greatest tan value is used to calculate the glass transition temperature. . According to this shift in Tg values, the filler working to promote change is likely a contributing factor.

d. Thermal Gravimetric Analysis of Bio filler epoxy composite

Figure 11 displays the thermal gravimetric analysis (TGA) of the bio-filler epoxy composite. The initial weight loss in the curves is attributed to the evaporation of water from the sample. Notably, the inclusion of fillers in the epoxy matrix improved the thermal stability of the polymer. The composite demonstrated thermal stability up to 540°C, with the sample containing 20% v/v fillers maintaining a stable residue content of 9%.

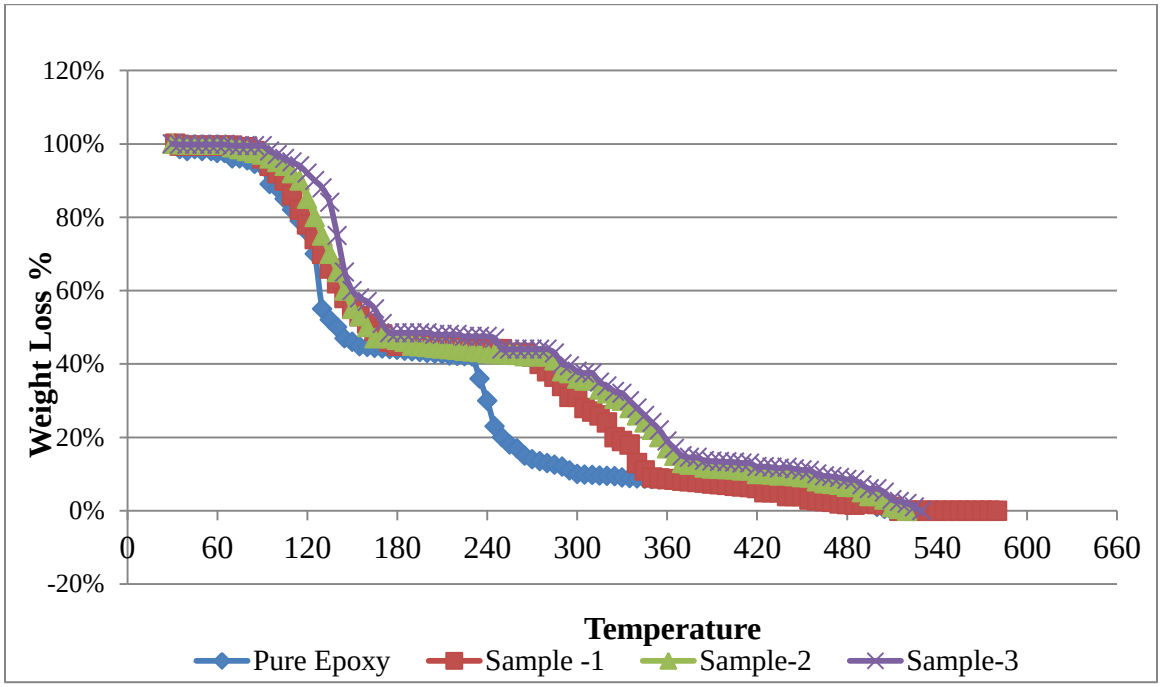

Figure 11 Thermal Gravimetric Analysis of Bio filler epoxy composite

This study focused on the development of various composites by incorporating snake grass, Casuarina, and cork fillers into epoxy resin. The research extensively analyzed the impact of these fillers on the mechanical properties of the epoxy resin.

- ✓ Through a comprehensive assessment of mechanical properties, it was determined that the composite containing 20% bio-fillers and 80% epoxy resin exhibited enhanced impact, tensile, and flexural strengths compared to composites with natural fillers.
- ✓ The mechanical properties revealed that the composite containing Sample 3 (10% snake grass, 5% Casuarina, 5% cork, and 80% epoxy) demonstrated superior values for impact, flexural, and tensile strengths.
- ✓ In the biodegradability test, a significant weight loss of 4 to 5 percent was observed over a period of 120 days, indicating the most substantial degradation.
- ✓ Incorporating agricultural products as fillers not only fulfills the quality requirements for polymer products but also improves their performance when compared to pure polymers.

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8. LIST OF PUBLICATIONS

a. **Parthasarathy, C**., S. Karthikeyan, R. G. Padmanabhan, and K. Kulothungan. "Experimental investigation of casuarina filler reinforced polymer composite." In International Conference on Sustainable Technologies and Advances in Automation, Aerospace and Robotics, (2022): 555-566

b. **Chandramohan, Parthasarathy,** Mayandi Kalimuthu, Karthikeyan Subramanian, Rajini Nagarajan, Farid F. Muhammed, Hamad A. Al-Lohedan, and Kumar Krishnan. "Mechanical and Thermo-Mechanical Behaviors of Snake Grass Fiber-Reinforced Epoxy Composite." Bioresources **19** (1) (2024).

c. **Parthasarathy, C**., K. Mayandi, S. Karthikeyan, and S. Senthilrajan. "Investigation of Snake Grass/Casuarina/Cork Filler Reinforced Bio Polymer Hybrid Composite." J. Environ. Nanotechnol **13** (3) (2024): 140-144.

d. **Parthasarathy, C**., K. Mayandi, S. Karthikeyan, and K. Kulothungan. "Experimental investigation of cork filler reinforced polymer composite." Materials Today: Proceedings (2024).